SEDIMENT TRANSPORT MODELLING AROUND BRIDGE AT SUNGAI TUI USING 1D QUASI UNSTEADY FLOW HEC-RAS

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ABSTRACT

Sungai Tui is located in the state of Pahang where huge amount of rainfall during monsoon season subjected to sediment transport process. The river responses by increased or decreased sediment carrying capacity, changing in channel cross section, erosion and deposition along the channel, which impact on river bank stability over a period of time. The research is to model sediment transport around bridge at Sungai Tui by using one dimensional (1D) quasi unsteady flow Hydrologic Engineering Centers River Analysis System (HEC RAS). There is few data required such as catchment area, precipitation data, geometric data and sediment data. The analysis is done using various method of transport function found in HEC RAS. For 5 years analysis of sediment transport, maximum erosion and deposition occurs at the depth 0.49m and 0.64m using Ackers-White; 0.50m and 0.76m using England-Hansen; 0.50m and 1.18m using Laursen; 0.50m and 1.12m using Meyer Peter Muller; 0.49m and 0.48m using Toffaleti; 0.50m and 0.76m using Yang and 0.50m and 1.18m using Wilcock. Erosion and deposition of sediment along the channel is not similar using various methods of transport function. In conclusion, sediment pattern can be predicted and analyzed using several methods in HEC-RAS software.

ABSTRAK

Kajian ini adalah untuk memodelkan pengangkutan sedimen di sekitar jambatan di Sungai Tui dengan menggunakan 1D aliran tak mantap kuasi HEC RAS. Sungai Tui terletak di negeri Pahang di mana sejumlah besar hujan semasa musim tengkujuh tertakluk kepada proses pengerakkan sedimen. Maklum balas sungai dengan ditambah atau dikurangkan sedimen keupayaan membawa, berubah dalam seksyen lintas channel, hakisan dan pemendapan di sepanjang saluran, yang memberi kesan kepada kestabilan bank dalam tempoh masa. Terdapat beberapa data yang diperlukan seperti kawasan tadahan, data pemendakan, geometri data dan data sedimen. Analisis dilakukan dengan menggunakan pelbagai fungsi pengangkutan sedimen terdapat di HEC RAS. Untuk analisis 5 tahun pengangkutan enapan maksimum hakisan dan pemendapan berlaku pada kedalaman 0.49 m dan 0.64 m yang menggunakan Ackers-White; 0.50 m dan 0.76 m yang menggunakan England-Hansen; 0.50 m dan 1.18 m yang menggunakan Laursen; 0.50 m dan 1.12 m yang menggunakan Meyer Peter Muller; 0.49 m dan 0.48 m yang menggunakan Toffaleti; 0.50 m dan 0.76 m Yang menggunakan dan 0.50 m dan 1.18 m menggunakan Wilcock. Hakisan dan pemendapan sedimen di sepanjang sungai tersebut adalah tidak serupa dengan menggunakan pelbagai fungsi pengangkutan sedimen.

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LIST OF SYMBOLS

π	Pie
A	Cross section area
Q	Discharge
q	Unit discharge of lateral flow
R	Hydraulic radius
P	Wetted perimeter
W	Top width
h	Mean flow depth
V	Velocity
i	Rainfall intensity
i_b	Infiltration rate
S	Channel slope
S_f	Slope of energy gradient
W_t	Fall velocity
D	Sphere diameter
ρ_s	Density
ρ	Density
g	Gravitational Constant
N	Kinematic viscosity of water
C_a	Concentration
$C^{'}$	Sediment concentration
z	Distance
w_a/KU_o	Rouse number
β	Ratio of diffusion coefficient for sediment over diffusion coefficient for momentum (eddy viscosity)
U_*	Shear velocity
K	Constant
W	Settling velocity
X	Sediment concentration
s	Specific gravity of sediments
d_s	Mean particle diameter

D	Effective depth
V	Average channel velocity
n	Transition exponent depending on sediment size
C	Coefficient
F_{gr}	Sediment mobility parameter
A	Critical sediment mobility parameter.
g_s	Unit sediment transport rate
γ	Unit weight of water
γ_s	Unit weight of solid particles
τ_0	Bed level shear stress
d_{50}	Particle size of which 50% is smaller.
C_m	Sediment discharge concentration, in weight/volume
d_s	Mean particle diameter
τ_c	Critical bed shear stress
k_r	Roughness coefficient
k_r'	Roughness coefficient based on grains,
g	Acceleration of gravity
d_m	Median particle diameter
R	Hydraulic radius
S	Energy gradient
g_{ssL}	Suspended sediment transport in the lower zone
g_{ssM}	Suspended sediment transport in the middle zone
g_{ssU}	Suspended sediment transport in the upper zone
g_{sb}	Bed load sediment transport
g_s	Total sediment transport
M	Sediment concentration parameter
CL	Sediment concentration in the lower zone
z	Exponent describing the relationship between the sediment hydraulic characteristics
n_v	Temperature exponent
C_t	Total sediment concentration

LIST OF ABBREVIATIONS

HEC RAS	Hydrologic Engineering Centers River Analysis System
HEC HMS	Hydrologic Engineering Centers Hydrologic Modeling System
USACE	US Army Corps of Engineers

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Malaysia has seen many changes in term of rapid urbanization. This development has accelerated effect on the river catchment areas will cause massive increase in the surface runoff and resulting in higher sediment transport. Sediment transport will be defined as the solid particles such as soil and rock that has been displaced passing each cross section for a specified period of time. Sediment transport is serious dangerous lead to damage the hydraulic structures along the river. When this phenomenon happens, it will not only affect river morphology but also decrease the channel capacity to convey the flood water to downstream and cause instability in the river channel.

Sediment in transport affects the quality of water and its suitability for human consumption or use in various enterprises. Sediment deposited in stream channels reduced the flood-carrying capacity, resulting in more frequent overflow and greater floodwater damage to adjacent properties. The deposition of sediment in irrigation and drainage canals, in navigation channels and floodways in reservoirs and harbors, on streets and highways and in building not only creates a nuisances but also inflicts a high public cost in maintenance removal or in reduced services (Bennett, 1939; Brune, 1958).

The phenomena of sediment transport occurred in rapid development in urban area. The emerging of urban area creates more impervious area. In addition, the amount of impermeable areas will increase for many purpose of landuse (Husan, 1991). The shifting from forest and open space areas to the commercial and industrial area caused substantial changes to the local ecosystem.

Sungai Tui is located in the state of Pahang where huge amount of rainfall during monsoon season subjected to sediment transport process. The river responses by increased or decreased sediment carrying capacity, changing in channel cross section, erosion and deposition along the channel, which impact on bank stability over a period of time. Monitoring and computing the sediment transport is necessary. The research is to model sediment transport around bridge at Sungai Tui by using 1D quasi unsteady flow HEC RAS. Modelling of sediment transport stimulate the sediment pattern around the bridge by using HEC RAS.

1.2 PROBLEM STATEMENT

Movement of sediment in suspension from upstream to downstream may cause several problems. The sediment transport as bed load rolling or sliding along the bed depends on the particle, size, shape, and specific gravity respect to velocity and turbulence. Cobbles move with high velocity and turbulence while silt particles move in low-gradient, low-velocity channels as muddy stream. Muddy stream increase the turbidity leads to decreases the growth of microscopic organisms that feed the fish. The study indicated people concern to fish in muddy stream because the effect of suspended sediment on the size, population and species of fish in a stream (Ellis, 1936). Huge amount sediment transport in river leads to stream morphology of the channel. The flood carrying capacity of the river channel is reduced by high level of sedimentation. This result in greater flood occurs.

1.3 OBJECTIVE OF RESEARCH

The main objective of this research can be outlined as follow:

i. to analysis the pattern of discharge (Rainfall Runoff Relationship).
ii. to stimulate and analysis the pattern of sediment transport around bridge at Sungai Tui, Pahang

1.4 SCOPE OF RESEARCH

The scope of study includes simulating the river using HEC RAS software using gathered data from local authorities. This study involved in the catchment area of Sungai Tui. In this study, a river network was established using the Google satellite images data and the analysis were carried out using river modelling and simulation. The river simulation was carried after all the data were inserted and the networks were created. The river flow from upstream to downstream was marked in the model.

1.5 EXPECTED OUTCOME

This research paper produces a pattern of sediment transport at Sungai Tui, Kuala Lipis, Pahang. Erosion and deposition can be evaluated form the analysis by using HEC RAS for one year, three years, five years and ten years. Sedimentation problem can be solved by increasing cross section of the river. Thus it decreases the flow rate of the river. Apart from that, defense structures such as reservoir, leeves, or weirs can be built to reduce the sediment transport to the downstream.

1.6 SIGNIFICANCE OF THE PROPOSED STUDY

River modelling is the best option to study the behaviors of and what are the influenced factors. By creating the river model based on the actual data and GIS image, the true phenomenon of what is really happened can be understood. The limitation of human activities along the river area could be established after a river simulating was conducted and the hazard risk map was produced. Through this study, the effect of massive water flow around the bridge to the sediment transport occurrences and behaviors could be determined. Thus, for the future, the appropriate early solution could be implemented for massive discharge.

This study is also expected to be able to help the responsible agencies and authorities to river and river basin management to apply more efficient approach for the purpose of analyzing and producing the best design practice in overcoming the sedimentation problems.

CHAPTER 2

LITERATURE REVIEW

2.1 OPEN CHANNEL HYDRAULIC

The learning of the physics of fluids flow in conveyances in which the following fluids forms a free surface and is driven by gravity. There are two types of open channel, natural open channel (river, creek) and artificial open channel (human construction; canals and flumes). The forms of flow in open channel are categorized with respect to time, space, viscosity, density and gravity.

2.1.1 Unsteady Flow in River

The depth varies with both time and space is unsteady flow involves the solution of the energy momentum and friction equations with time. It can be analysed as gradually varied steady flow because the flow is sufficiently close to steady flow.

2.1.2 One Dimensional River Continuity Equation

The figure 2.1 below defines a river reach with cross section area, A, top width W, wetted perimeter P, hydraulic radius $R_h = A/P$, and mean flow depth $h = A/W$. Product of the area A and mean flow velocity V, produce the total discharge Q; the unit discharge of the lateral flow is q_l. The rainfall intensity is i, and the infiltration rate through the wetted perimeter is i_b. The net volumetric flux leaving the control volume is $(\partial Q/\partial x)\,dx + i_b P\,dx$. The net volumetric flux entering the control volume is $q_l\,dx + iW\,dx$. The difference between entering and leaving volumetric fluxes corresponds to volumetric storage $\partial A\,dx = \partial(Wh)dx$ per unit time ∂t .

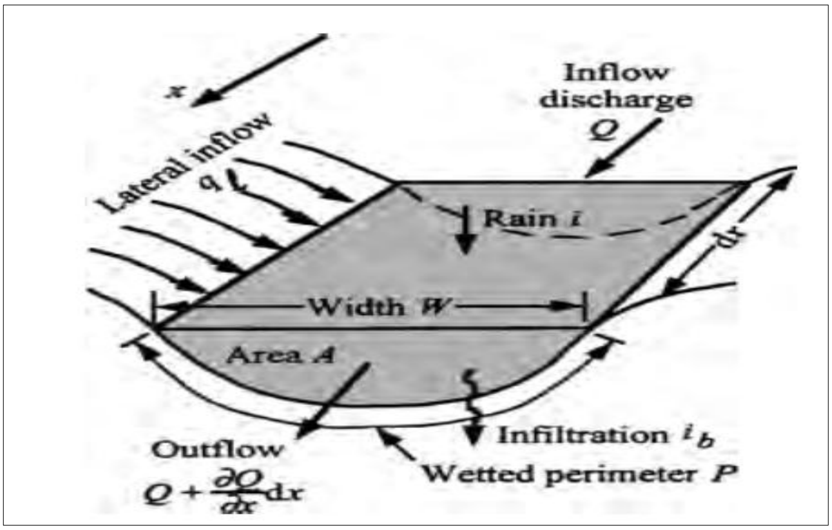

Figure 2.1: Continuity of river reach

Sources: Julien P.Y. (2002)

After dividing by dx, we easily demonstrate that

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} + i_b - iW - q_l = 0 \quad (2.1)$$

where i_b is the rate of infiltration through the wetted perimeter P, i is the rainfall intensity through the reach-averaged river width W, A is the reach-averaged cross-sectional area, and q is the unit discharge of lateral inflow. For an impervious channel (i_b=0) without rainfall (i =0) and without lateral inflow (q_l = 0), the1D equation of continuity simply reduces to

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad (2.2)$$

This simple differential equation that expresses conservation of mass is widely used in the analysis of floodwave propagation.

2.1.3 One Dimensional Momentum of River

However, for most practical purposes, the spatial variations in lateral and transverse directions can be neglected and the flow in a river system can be approximated as a one-dimensional process along the longitudinal direction (i.e., in the direction of flow). The Saint Venant equations that were derived in the early 1870s by Barre de Saint-Venant, may be obtained through the application of control volume theory to a differential element of a river reach. The Navier-Stokes equations can be simplified for one-dimensional flow. Assumption made in Saint Venant equations as:

a) The flow is one-dimensional. The water depth and flow velocity vary only in the direction of flow. Therefore, the flow velocity is constant and the water surface is horizontal across velocity is constant and the water surface is horizontal across any section perpendicular to the direction of flow.

b) The flow is assumed to vary gradually along the channel so that the hydrostatic pressure distribution prevails and vertical accelerations can be neglected. The channel bottom slope is small and the channel bed is stable such that there is no change in bed elevations in time. The fluid is incompressible and of constant density throughout the flow.

c) The Manning and Chezy equations, which are used in the definition of channel resistance factor in steady, uniform flow conditions, are also used to describe the resistance to flow in unsteady, non-uniform flow applications.

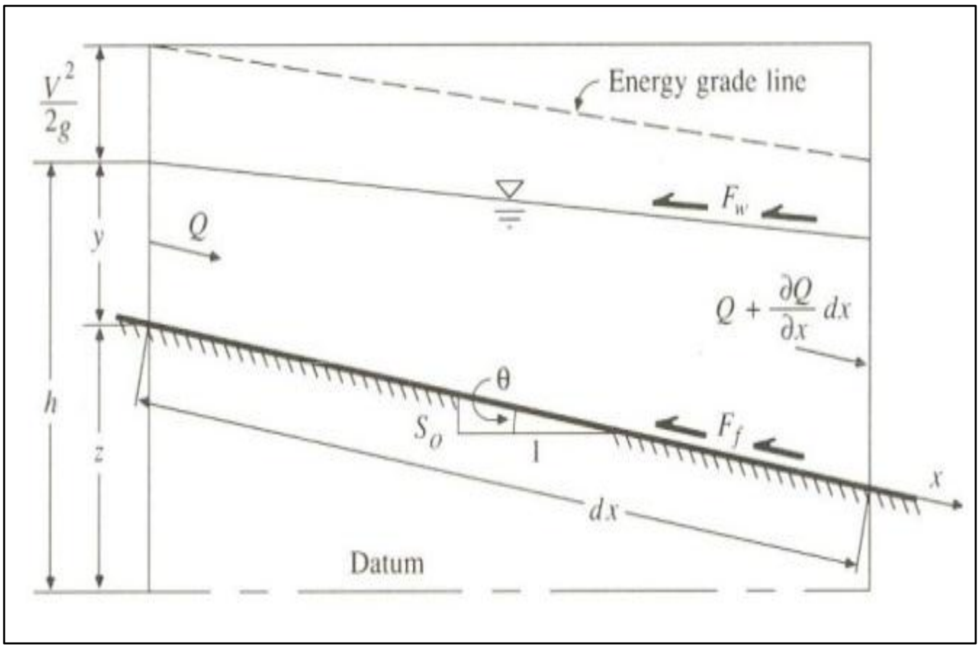

Figure 2.2: Cross section view

Sources: Julien P.Y. (2002)

These equations are the governing equations of one dimensional unsteady flow in open channels and were originally developed by the French scientist Barre de Saint-Venant in 1872.

$$\frac{\partial Q}{\partial t}+\frac{\partial(\beta Q^2)}{\partial x}+gA\left(\frac{\partial h}{\partial x}+S_f+S_e\right)-\beta qv_x+W_fB=0 \qquad (2.3)$$

2.2 SEDIMENT

Sediment is hard or loose material found mainly on the bottom of the river. There are many forms and sizes of sediment. It transported by fluid flow and which eventually is deposited as a layer of solid particles on the bed. The early studies on sediment transport in rigid bed were research by (Craven, 1953; Valentine, 1955; Lauren, 1956). In early stage of research, initial motion on sediments was studies and transporting capacity of the flow was determined for the limit of deposition.

2.3.1 Sediment Transport

No sediment was moved at very low velocities but sediment will transport along the bed at some higher velocity. Motions of sediment in different modes which exist in a stream are defined as follow. Individual grain on the channel bed will roll and slide intermittently along the streambed in the direction of the flow. The sediment so moved is defined as the contact load of the stream. Some grain may also move above the bed surface by saltation. Movement in this mode is describe as saltation load of the stream that occurs when one grain, causing it to jump upward and the fall back toward the bed. Some of the grain transported as suspension if the flow velocity is increasing and the jumps executed by the grain will occur more frequently.

These rolling, sliding, suspension and saltation motions move sediment in a streambed and characterize the transport as bed load. The weight of the sediment related to flow velocity in a stream. In stream channel the transport of sediment as the bed load has been widely studied and a number of empirical equations have been proposed (Einstein, 1942; Meyer-Peter and Muller, 1948; Van Rijn, 1984; Ackers and White et al, 1978).

Motion of sediment in suspension by turbulent eddies are mostly finer-grained. Suspended load is the particles transport within the water column call. If the turbulent is present, there may be continues exchange of sediment between the bed loads of the river. Part of the suspended load may be colloidal clays, which remain in suspension for a very long period of time, depending on the type of clay and water chemistry.

Finest sediment particles in transport are wash load. An inflow of fine sediment in suspension which remain in suspension describe as wash load. The concentration of wash load in suspension is fundamentally independent of hydraulic condition in the stream. Thus, it cannot be calculated using hydraulic parameters such as velocity or discharge. The concentration of wash load is usually a function of supply. As the watershed and banks can transport, the stream can take as much wash load. Figure 2.3 shows various loads within a stream and motion of sediment transport. Figure 2.4 shows sediment transport classification.

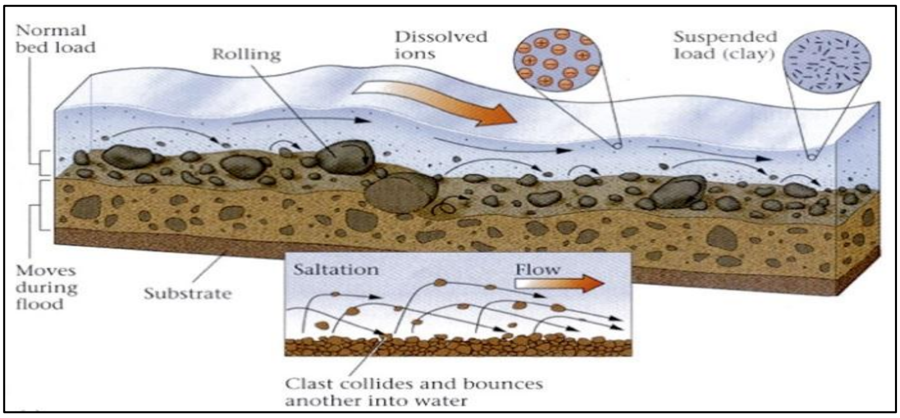

Figure 2.3: Various loads within a stream

Sources: Jansen et al. (1979)

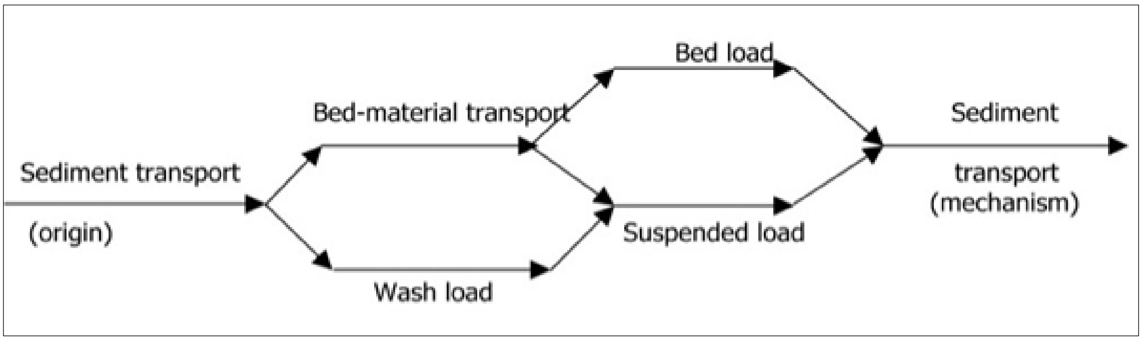

Figure 2.4: Sediment transport classification

Sources: Jansen et al. (1979)

2.3.2 Cohesive and Non-cohesive Sediment

Cohesive and non-cohesive sediment have differences in the natural characteristic. The major discrepancies between suspended cohesive sediment and suspended non cohesive sediment depend on calculation of the settling velocity or fall velocity of sediment, the interchange across the sediment water interface and bed compaction consideration (Van Rijn, 1984). Particles size of cohesive sediment that are smaller than 62µm. In the case, the effect of the flocculation makes settling velocity a function of sediment concentration (Van Leussen, 1994).

Cohesive sediment is the clay-sized materials that are composed, which have strong inner particles forces due to their surface ionic charges. The behavior of sediment dominant by inter particles forces. Its surface area per unit volume (i.e. specific surface area) increases when particles size decrease. There is no clear boundary between cohesive sediment and non-cohesive sediment. The definition is usually site specific. In overall finer sized grains are more cohesive. Sediment sizes smaller than 2 µm (clay) are usually considered cohesive sediment. Silt (2µm-60µm) is well-thought-out to be between cohesive and non-cohesive sediment. The cohesive properties of silt are predominantly due to the presence of clay. Coarse non-cohesive sediment is defined by sediment of size larger than 60 µm. Hence in engineering practice, silt and clay well known be cohesive sediment.

Cohesive sediment contains of organic minerals and inorganic minerals (Hayter, 1983). The organic material is present as animal detritus and plant. There are two types of inorganic minerals such as clay mineral (e.g. illite, kaolinite, montmorrillonite, silica) and non-clay minerals (e.g quartz, mica, and carbonates, among others). Sediment especially cohesive sediment is associated to water quality in stream. Sediment concentration decrease the quality of the water in a stream makes pollutant. In addition, chemicals and wastes are adsorbed to the sediments, are sometimes a water quality concern. The increase in turbidity causes the sunlight evasion to penetrate and decrease the food availability, thus affecting aquatic life. Therefore from the environmental point of view sediment transport is important because there is a link between the presence of sediment and pollutant concentrations (Ashley et al,1991).

2.3.3 Properties of sediment

The discipline of sediment transport interrelated between flowing water and sediment. The study of sediment transport is essential for understanding of the physical properties of water and sediment or sediment is its size. Shape and roundness are vital to the diameter of the grain particles. Shapes define as form of particle whereas roundness defines as the sharpness or radius of its curvature of its edges. For example, a flat particle have a smaller fall velocity than a sphere, but hard for bed load to transport.

Sediment in a stream is naturally occurring material of many different sizes and shapes. The particle size distribution is usually represented by a plot weight percentage of the total sample which is smaller than a given size plotted as function of the particle size. The typical sediment size d_{50} is meant by the sediment size for which 50% by weight of the material is finer. D_{50} is generally used as the characteristic grain size. Due to environmental conditions, the size distribution of cohesive sediment (e.g. clay, silt) may vary to which the sediments have been exposed and also the measures that are used to determine their size distribution. Sediment are classify into two categories: cohesive sediment (e.g. clay and silt) and non-cohesive sediment (e.g. sand, gravel, cobbles and boulders). A typical sediment size classification is shown in table 2.2.

Table 2.1: Sediment size classification

	Class Name	Size Range (mm)
Clay	Very fine clay	0.00024-0.0005
	Fine clay	0.0005-0.0010
	Medium clay	0.0010-0.0020
	Coarse clay	0.0020-0.004
Silt	Very fine silt	0.004-0.008
	Fine silt	0.008-0.016
	Medium silt	0.016-0.031
	Coarse silt	0.031-0.062
Sand	Very fine sand	0.062-0.125
	Fine sand	0.125-0.250
	Medium sand	0.250-0.500
	Coarse sand	0.500-1.000
	Very coarse sand	1.000-2.000

Sources: Vanoni (1977)